**CO2-free Hydrogen production businesses, getting started in the world targeting a huge market.**

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Projects aimed at the realization of "hydrogen society", in which hydrogen that does not emit carbon dioxide ($CO_2$) when burnt serves as an energy source in a large scale, have been started in the world. (Figure 1) The market size of hydrogen infrastructure-related industries is expected to reach 160 trillion yen in 2050 (according to a survey conducted by Nikkei BP CleanTech Institute). The approaches that are attracting attention as essential ones for achieving such hydrogen society are projects for hydrogen production without causing $CO_2$ emissions ($CO_2$-free hydrogen production). The background to this is the pledge to "reduce the amount of $CO_2$ emissions of the entire developed nations by 80% by 2050", an agreement made among the G8 nations at the 2009 L'Aquila Summit. People involved in the hydrogen infrastructure have images of the future of the hydrogen society in their mind based on this agreement, and for achieving this, generating $CO_2$-free hydrogen is required as a precondition.

Figure 1: A project aimed at hydrogen society. The photograph shows a hydrogen station of Toyota Ecoful Town and Toyota Motor Corporation's fuel cell vehicle.

Hydrogen rarely exists in nature, and it usually exists as a form of a compound such as hydrocarbons and water. Therefore, energy needs to be added to these compounds in some sort of way to produce hydrogen. Currently, by-product hydrogen produced in factories covers the demand, and in case of a shortage, hydrogen is produced by reforming fossil fuels. In these methods for producing hydrogen, CO2 needs to be emitted in processes of adding energy.

As approaches for addressing this, attempts to produce CO2-free hydrogen are becoming active in two directions; 1) water electrolysis using electricity from renewable energy sources and 2) achieving CO2-free reformation or gasification of fossil fuels by having a process of "CCS (Carbon dioxide Capture and Storage)" (separate, capture, and store CO2 generated during processes such as reformation and gasification before emission into the air).

*28 projects that are on-going in the world

According to "A Comprehensive List of the World's Hydrogen Infrastructure Projects" (published on Oct. 24th, 2013), a report that lists the results of a survey conducted by Nikkei BP CleanTech Institute on the world's major hydrogen infrastructure-related projects, among 70 major projects, the number of the projects aimed at CO2-free hydrogen production reached 28.

Among them, the number of the projects to implement CO2-free hydrogen production using renewable energy reached 26. They can be classified as below; projects on hydrogen production from wind power generation accounted for the largest number of 10, the number of projects on the production of hydrogen by electrolyzing water using renewable energy in general was 6, 6 projects also on the production from biogas were counted, and 3 on the production from solar photovoltaic power generation.

Only one project to produce hydrogen from water power generation is listed, but this is because these kinds of projects have already been spread in some fields, and only a progressive one for using it for electrical supply and demand was picked-up. In addition to them, 2 projects to achieve CO2-free production by implementing CCS in combination with gasification and reformation in regions where coalfields and natural gas fields are located were counted.

*Hydrogen utilization from wind power generation that is lively in Germany

A noticeable one among them is a project for producing hydrogen by electrolysis using wind power generated electricity in Germany. Germany is especially promoting the introduction of wind power generation, even among renewable energy sources as it has already taken steps toward nuclear-free power generation, and many of the wind power plants are concentrated in Northern Germany.

As there is no large demand for electricity in Northern Germany, the electricity needs to be transmitted to the industrial zone, Southern Germany, but the construction of high-voltage power transmission lines has been delayed. Therefore, projects to produce hydrogen from the surplus electricity generated by wind power in Northern Germany, and utilize it have been increasing.

For example, in the "Prenzlau wind power-to hydrogen project" that is on-going in Prenzlau in Brandenburg located in the north at a distance of 120 km from Berlin, the capital city of Germany, usually, 6 MW of wind-generated electricity in total is sent to a power system network. However, in case extra electricity is generated because of a smaller demand for electricity during off-peak times such as nights, water is electrolyzed for producing hydrogen, and stored in a tank.

The stored hydrogen is mixed with combustible biomass-produced gases (biogas) such as methane, and supplied to a cogeneration (combined heat and power) system, as necessary. In the cogeneration equipment, the electricity is sent into an electric power system network, and the exhaust heat is sold to local heating suppliers. Activities such as supplying a part of hydrogen to the facilities in locations like inside the city of Berlin, such as hydrogen stations for fuel cell vehicles (FCV) and hydrogen cars, have been initiated.

Also among "Hythane" (hydrogen-blended town gas) projects to use hydrogen as a fuel by blending it into methane of town gas, projects to utilize hydrogen from wind power generation have been increasing. As a typical example, there is German "Power to Gas". Energy companies such as E.ON and Greenpeace Energy transform water into hydrogen with electrolysis using surplus electricity generated by wind power, and supply it to the existing gas grids.

These methods provide not only effective use of the surplus electricity but also decreases in emissions of harmful substances such as SOX (sulfur oxide) and NOX (nitrogen oxide) by adding clean hydrogen. As the existing town gas infrastructure can be utilized in these methods, the activities have been considered to trigger the transition to the hydrogen society.

*Produce methane from CO2-free hydrogen

Instead of blending hydrogen into town gas as a form of itself, efforts to produce methane itself, a constituent of town gas, from hydrogen are also becoming active. In Germany, Solar Fuel created a plant to produce hydrogen with water electrolysis using electricity from renewable energy sources and produce methane by the reaction of the produced hydrogen with CO2 in the air, and is working on demonstration experiments to achieve this.

Figure 2: Audi’s "e-gas" plant

In 2009, this company operated a prototype with renewable energy output of 25 kw, and succeeded in producing methane at 40% of efficiency. In 2013, they scaled up the prototype to 20 MW, and are aiming to put it into full-scale practical use. In case of this company, the target is to supply the produced methane to the natural gas pipeline (gas grid) as it is. There are the advantages that the town gas infrastructure can be utilized, and that town gas can be CO2-free in this project.

An attempt to utilize the renewable energy-derived hydrogen and the methane produced with CO2 in automobiles has also been initiated.

It's "Audi e-gas project" carried out by an automobile manufacturer, Audi. In this project, a facility that has a capacity to generate hydrogen with water electrolysis using 6 MW of electricity, and produce 1,000 tons of methane gas per year from the generated hydrogen and $CO_2$, will be put into full-scale operation in the fall of 2013. (Figure 2) They have plans to use the produced methane gas as fuels of the CNG (compressed natural gas) cars they sell and supply it to public gas networks.

*Utilize hydrogen from solar photovoltaic power generation in local areas and buildings

Efforts to generate hydrogen using solar photovoltaic-generated electricity are also increasing gradually. One of the famous projects is "MYRET platform project" in Corsica in France. In this project, experiments to produce hydrogen by electrolyzing water using surplus electricity from a solar photovoltaic power generation system, generate electricity with fuel-cells for using during time of peak demand and for leveling the solar photovoltaic-generated electricity, and transmit the electricity to a power system network in Corsica are in progress.

In case of solar photovoltaic power generation, as it has been introduced also in customers' facilities such as buildings and housing, projects to convert the solar photovoltaic-generated electricity into hydrogen in these facilities and utilize it have also been initiated. For example, at Griffith University in Australia, solar photovoltaic panels have been mounted on the roof. During the daytime, the electricity is used directly in the facility while sunlight is available, and the surplus electricity is stored in a storage battery for use in electrolysis for hydrogen production. The generated hydrogen is stored in metallic alloys for hydrogen storage.

This is working in a system where the electricity stored in the storage battery is used mainly for driving air conditioners at nighttime, and the hydrogen supplies electricity through fuel-cells on cloudy or rainy days. They say that hydrogen alone can cover one day's worth of electricity for the facility.

*$CO_2$-free hydrogenation by CCS from fossil fuels

As to the methods to produce hydrogen from fossil fuels, studies, on $CO_2$-free methods achieved by local CCS in the regions where natural gas fields and coalfields are located, are in progress. In the long term, basic researches on using stored $CO_2$ as a carbon resource have also been started. In the field of this method, Japanese companies such as Chiyoda Corporation and Kawasaki Heavy Industries are leading.

Chiyoda Corporation is developing a method to transport hydrogen produced in places such as overseas natural gas fields by using methylcyclohexane (MCH) created by hydrogenation of toluene. (Figure 3) MCH is a room-temperature and normal-pressure liquid that can reduce the volume of gaseous hydrogen into 1/500. Even though energy is required in the process of extracting hydrogen, this method has the advantage that the existing infrastructure such as chemical tankers and tank trucks can be utilized.

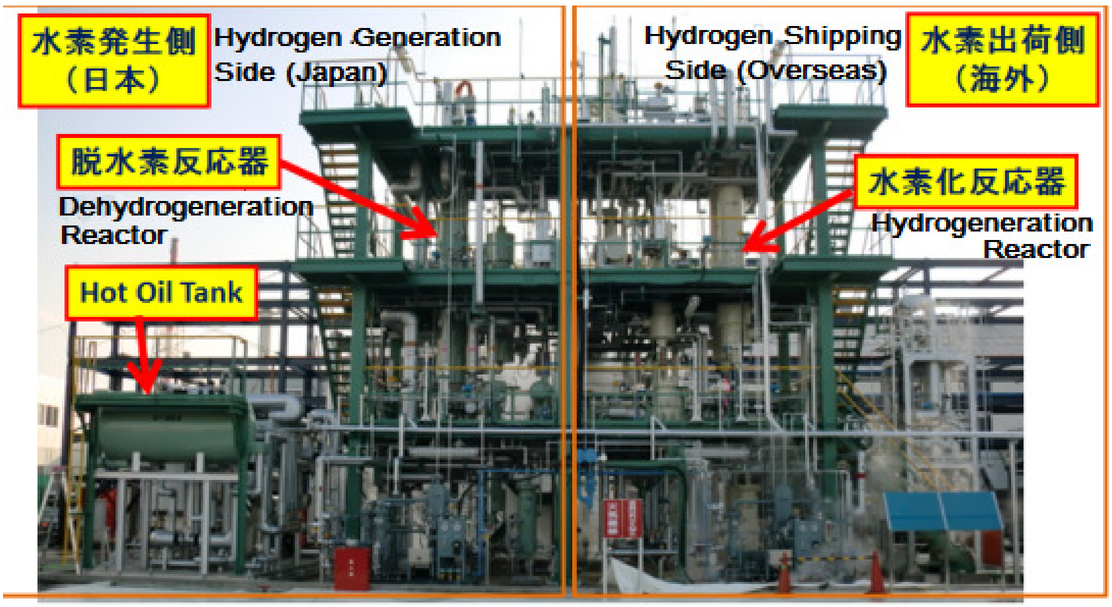


Figure 3: The demonstration plant for methylcyclohexane.

Constructed a 50 Nm3/h demonstration plant in a R&D center located in Yokohama in March, 2013. (Exhibitor: Chiyoda Corporation)

On another side, Kawasaki Heavy Industries is pushing ahead with a business to use brown coal that is mined in coalfields in Australia as materials to locally produce $CO_2$-free liquid hydrogen in combination with CCS and transport it to Japan by ship. (Figure 4) They say that liquid hydrogen was chosen because of its advantages that it does not require the processes such as the removal of impurities, and that it will be available for use immediately after the transportation. A new carrier for transporting liquid hydrogen needs to be developed because of a new specification such as cooling at lower temperatures than LNG carriers, but Kawasaki Heavy has already worked out the specifications, and considers that the industrialization is possible.

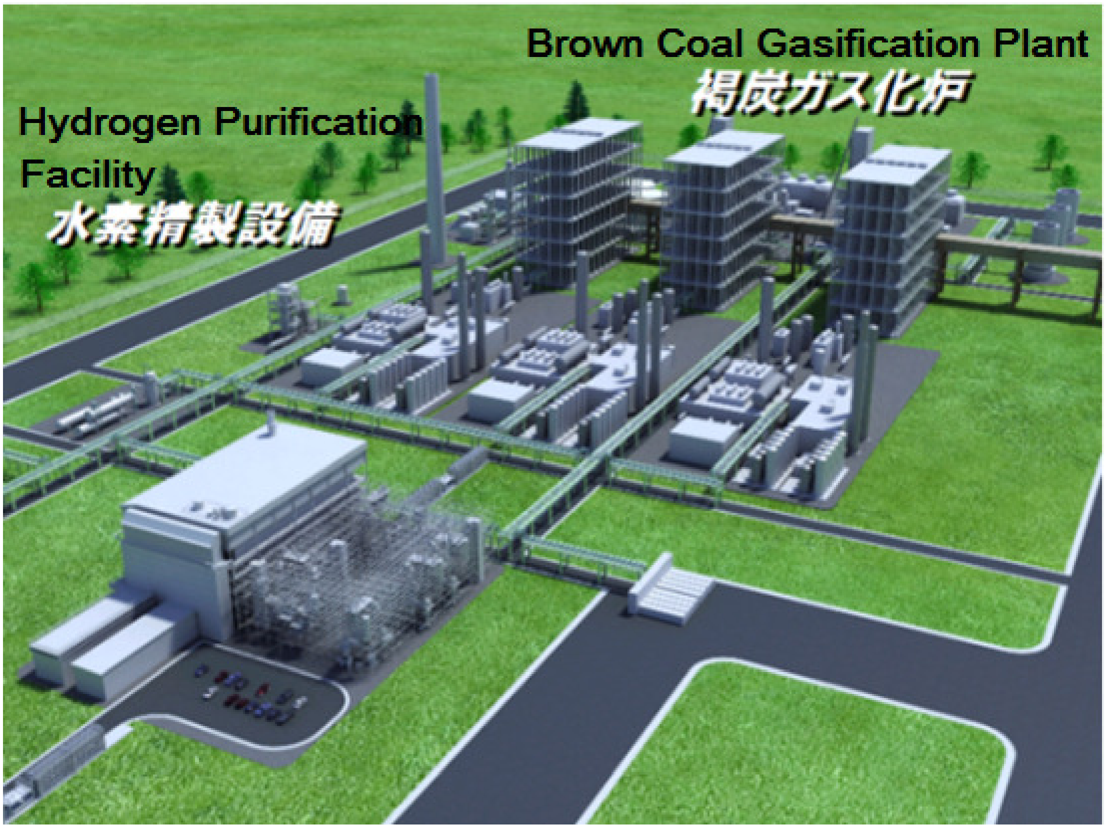


Figure 4: An image of hydrogen production equipment by a FS (feasibility study) on a commercial chain with its full-capacity operation targeted for 2030. (Exhibitor: Kawasaki Heavy Industries)

Chiyoda Corporation states that it will start its hydrogen transportation business at the end of 2015, and Kawasaki Heavy Industries says that the commercial chain will commence operating at full capacity in 2030. Both companies state that they will set the hydrogen export price at around 30 Yen per Nm3 (normal cubic meter) at the beginning of the operation, and have ideas of providing low-cost CO2-free hydrogen in large quantities. Getting these projects on track will bring the potential for Japan to lead the world's hydrogen businesses.

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